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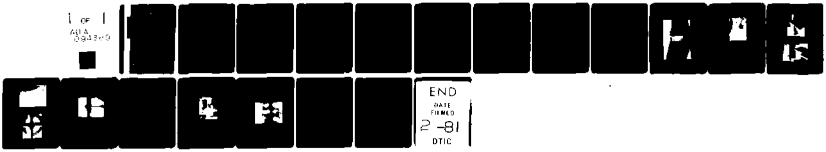

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Mechanical Engineering Technical Memorandum 397

AN INVESTIGATION INTO THE ICE BUILD UP ON THE NOZZLE MATRIX OF THE 'PEGASUS' ICING SPRAY SYSTEM

C.S. WILSON and P.B. ATKINS

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AN INVESTIGATION INTO THE ICE BUILD UP ON THE NOZZLE MATRIX OF THE 'PEGASUS' ICING SPRAY SYSTEM.

10 C.S. WILSON ~~(*) and~~ P.B. ATKINS

SUMMARY

During the course of flight experiments using an airborne icing spray system fitted to a Nomad aircraft, ice build up on the spray matrix was encountered after prolonged spraying at high liquid water contents at low temperatures. The problem was found to be caused by airflow separation on the fairing to the matrix tubing which induced water droplets back onto the fairing. Tests on a ground icing rig showed that ice build up could be eliminated by redesigning the fairing to prevent the airflow separation.

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DOCUMENT CONTROL DATA SHEET

Security classification of this page: UNCLASSIFIED

1. DOCUMENT NUMBERS a. AR Number: AR-001-786 b. Document Series and Number: Mechanical Engineering Technical Memorandum 397 c. Report Number: ARL-MECH-ENG-TECH-MEMO-397	2. SECURITY CLASSIFICATION a. Complete document: UNCLASSIFIED b. Title in isolation: UNCLASSIFIED c. Summary in isolation: UNCLASSIFIED

3. TITLE:

AN INVESTIGATION INTO THE ICE BUILD UP ON THE NOZZLE MATRIX OF THE 'PEGASUS' ICING SPRAY SYSTEM

4. PERSONAL AUTHORS: C.S. WILSON (On attachment to A.R.L. from G.A.F.) and P.B. ATKINS	5. DOCUMENT DATE: December, 1979 6. TYPE OF REPORT AND PERIOD COVERED:
7. CORPORATE AUTHOR(S): Aeronautical Research Laboratories	8. REFERENCE NUMBERS a. Task: DST 79/080
9. COST CODE: 42-1895	b. Sponsoring Agency: DST
10. IMPRINT: Aeronautical Research Laboratories, Melbourne	11. COMPUTER PROGRAM(S) (Title(s) and language(s)):

12. RELEASE LIMITATIONS (of the document):

Approved for Public Release.

12.0 OVERSEAS:	N.O.		P.R.	1	A		B		C		D	E

13. ANNOUNCEMENT LIMITATIONS (of the information on this page):

Nil.

14. DESCRIPTORS:		15. COSATI CODES:
Nomad aircraft.	Ice formation	0812
Spray nozzles	Ice prevention	2004
Fairings	Boundary layer separation	

16. ABSTRACT:

During the course of flight experiments using an airborne icing spray system fitted to a Nomad aircraft, ice build up on the spray matrix was encountered after prolonged spraying at high liquid water contents at low temperatures. The problem was found to be caused by airflow separation on the fairing to the matrix tubing which induced water droplets back onto the fairing. Tests on a ground icing rig showed that ice build up could be eliminated by redesigning the fairing to prevent the airflow separation.

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A

1. INTRODUCTION

During the course of flight experiments using an airborne icing spray system (Ref. 1), the presence of ice build up on the spray matrix was noted. There was a possibility that this may have been the cause of an engine flame out if the ice had broken loose from the matrix and entered the test aircraft engine intake. After prolonged spraying (1 hour) at low outside air temperature (-20 deg.C) and at high delivered liquid water contents (2-3 gm/cu m.) the ice growth and subsequent build up were observed at the matrix intersections and occasionally around the spray nozzles. This memorandum describes the work done to alleviate this problem.

2. THE PROBLEM

Fig. 1 shows the spray matrix in the spraying position beneath the NOMAD N22B aircraft which had been converted to an icing spray tanker. The matrix consisted of a 1.2m (4 ft.) square frame of 50 mm (2 in.) diameter tube, faired on the trailing edge, with 47 spray nozzle positions. High pressure, hot air from the aircraft engine's compressor bleed was fed through the tubes forming the frame, and the water was delivered to the nozzles under pressure through 6 mm diameter plastic tubing located within the fairing of the 50 mm air tubes.

After prolonged flying at high water delivery rates and at low outside air temperatures, ice was observed to form at the fairing intersections and around some nozzles, (Fig. 1). This build up of ice has been estimated to extend for 150 mm (6 in.) and sometimes to weigh as much as 0.9 kg. (2 lb.).

During the course of the flight experiments with a test aircraft formating in the icing spray, a number of ice strikes were reported by the test aircraft crew and engine flame out occurred on one occasion. Whilst there may be some doubt as to whether these strikes were caused by ice shedding from the matrix, or from ice shedding from the test aircraft spinner or propeller, the occurrence of the engine flame out, which was a much more serious situation, caused this investigation to be undertaken.

Calculations show that if in fact a piece of ice with a cross sectional area of the order of 2600 sq.mm (4 square ins.) were to be shed from the spray matrix, then its subsequent path could take it to the area of the formating aircraft's engine intake due to the close formation used (9-15 m separation), and the propeller blade passing frequency would allow this ice to pass into the intake. It is possible that such a piece of ice could lodge in the engine intake, for a sufficient time before melting, so that the subsequent flow distortion could cause the engine to surge, resulting possibly in a flame out. Subsequent melting of the ice would leave no visible evidence of its presence.

Fig. 2 shows the type of build up of ice which could occur. This example was obtained by running in the A.R.L. ground test icing rig (Ref. 1) under very adverse conditions but it is nevertheless indicative of possible ice accretion on the aircraft spray matrix.

3. EXPERIMENTAL SET UP

Two test models were made:-

(a) One to represent the intersection of the vertical and horizontal tube and fairing, built to the same build standard as on the icing spray matrix (Fig. 3a).

(b) A section of spray matrix incorporating a nozzle and supply tubes for air and water, shown in Fig. 3b in the icing rig with the nozzle spraying.

Both models were tested in the exit from a centrifugal blower, the nozzle model thus mounted shown in Fig. 4a, and the intersection model (after modification) shown in Fig. 4b. This blower was run at a speed to give the same Reynolds number as in flight at representative test altitudes, and incorporated a flow straightener upstream of the exit to improve the quality of the air flow. This intersection model was only tested using flow visualisation techniques, and only in the blower rig.

The nozzle model was tested in the icing rig under representative icing conditions; it was equipped to spray representative quantities of water and hot air in an airstream of 54 m/s (120 mph) at -10 deg.C.

Two different types of air blast nozzle were used during the tanker trials, a commercially available nozzle (supplied by Spraying Systems Company, Illinois, U.S.A.) which was used for high liquid water content tests, and an A.R.L. designed nozzle which was used for low liquid water content tests.

4. DESCRIPTION OF TESTS

Initial flow visualisation testing, with wool tufts on the intersection model, identified a large separation area of approximately 180 mm (7 in.) diameter behind the intersection. An appreciable flow of air was noted to be induced through the vertical sections (i.e. those having open ends at the intersection (see Fig. 3a). It was concluded that, should any water droplets find their way into this region, then they would certainly build up into an ice deposit very quickly under freezing conditions.

Experiments aimed at eliminating this intersection separation necessitated modification to add a substantial fillet and fairing (Fig. 5).

Whilst this modification would have largely removed the intersection ice build up problem, and would have substantially reduced the aerodynamic drag of the matrix, it was not considered to be a viable solution from the points of view of time scale and cost.

To investigate the basic cause of the water presence at the intersection, the nozzle model was mounted in the dry blower exit (Fig. 4a). Water was not supplied to the nozzle in these tests, but the nozzle air mass flow was increased to substantially simulate the water flow, and maintain the flow entrainment effect of the air/water combination.

The arrangement of air and water supply tubes, nozzle and fairings is shown in Fig. 6. The area of recirculation due to aerodynamic separation is shown in this figure; this not only caused entrainment of water drops onto the fairing in the region of the cut out at the trailing edge, but also allowed the entrained water to run inside the fairing trailing edge. It was thus concluded that this water was draining, not only under gravity but

also due to pressure difference, to the fairing intersection where it was freezing.

The hollow vee opening at the trailing edge close to the nozzles was blocked off with tape to prevent this drainage taking place, and this did in fact largely prevent ice build up at the fairing intersection. However it also had the effect of increasing the ice build up at the trailing edge in the region of the vee cut out, to an unacceptable level.

Experiments to reduce ice adhesion to the fairing surface were made using teflon tape, (Fig. 7), a commercially produced fluid called "ICEX" (normally used on wing de-icing boots to assist ice clearance), and "ICEX" on a rubber mat; all proved unsatisfactory.

Experiments aimed at producing the nozzle spray further downstream by fitting a 25 mm (1 in.) extension to the nozzle body, were only partially successful since the separation area was so extensive that it still entrained spray droplets.

To reduce the aerodynamic separation caused by the bluff shape of the nozzle, the nozzles (both commercial and ARL design) were faired with plasticene (Fig. 8). Because of poor heat conduction through the plasticene, ice grew on these faired parts more quickly than on the metal. An A.R.L. nozzle was turned down to provide a smooth contour, but with no better result.

Attention was then directed to conditions on the upstream part of the matrix which proved to be the root cause of the problem. From flow visualisation experiments in the blower rig, using wool tufts and titanium dioxide in oil, it was ascertained that separation was taking place at the lap joint of the fairing and the air supply tube (Fig. 6). An attempt to eliminate this separation by use of vortex generators was unsuccessful.

A wrap around fairing (Fig. 9) was designed and made to provide a smooth contour at least as far aft as the nozzle. Areas just forward and aft of the nozzle were faired smoothly with tape, and arranged to prevent any water ingestion into the fairing. This modification was tested in the blower outlet using titanium dioxide and oil, and although the flow remained attached to the trailing edge over a range of approximately +10 deg. to -10 deg. incidence, a laminar separation bubble was present at the 20% chord position. When tested in the icing rig, ice formed on the fairing at this laminar separation position, but was physically removed during the test. The justification for doing this was based on the fact that such icing had not been observed in flight, and that the moisture content level in the icing rig (causing this ice build up) was much higher than that at altitude under the flight test condition. This modification performed extremely well under icing conditions, producing very little ice growth on the fairing after prolonged exposure.

5. CONCLUSIONS

(1) Ice growth on the spray matrix intersection of the NOMAD tanker aircraft was caused by water induced into the matrix fairing from the spray nozzles.

(2) The most effective way of preventing both intersection ice build up and fairing ice build up near the nozzles, was to replace the existing fairing with a full wrap round fairing. The reasons for this are first, to prevent aerodynamic separation around the bluff air supply tubing of the matrix which caused fine water droplets from the spray nozzle to be entrained forward onto the fairing, and second, by sealing any gaps in the fairing, to prevent migration of water to the intersection.

(3) A solution which would be less sensitive to the separation problem, would be to use a fairing at the leading edge of the tubing giving an aerodynamic shape of higher fineness ratio.

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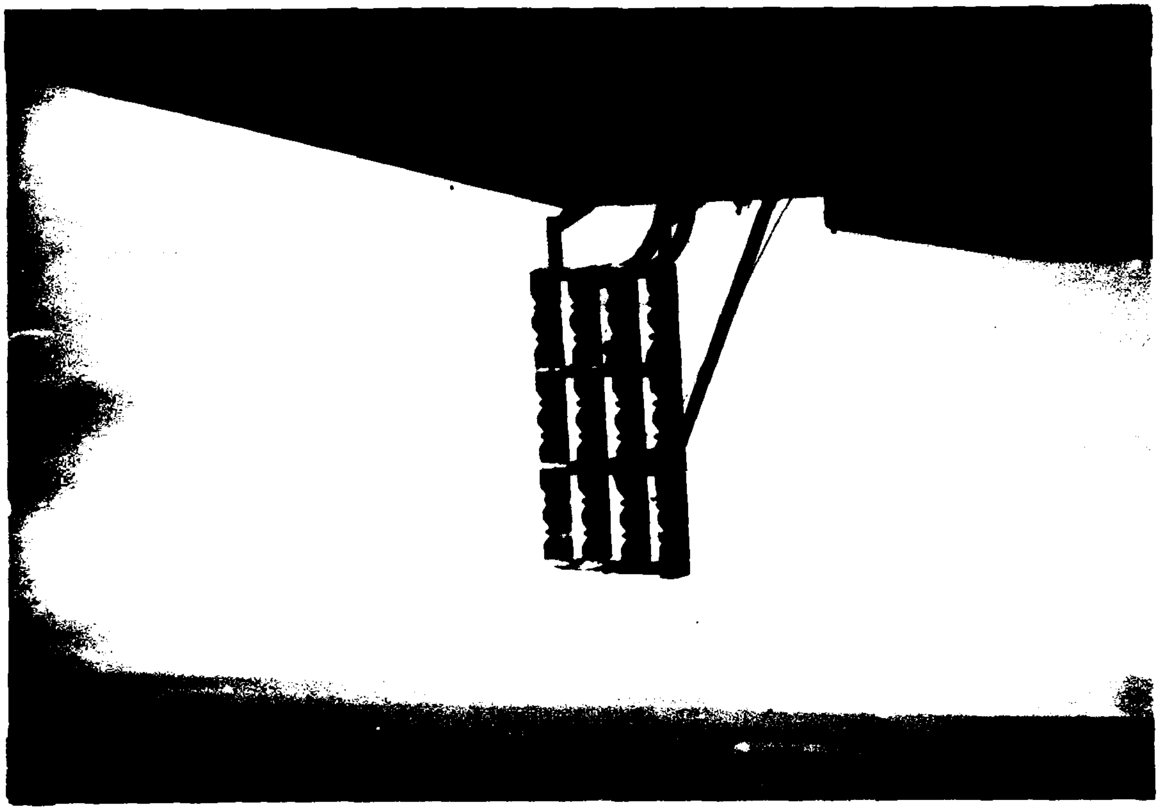
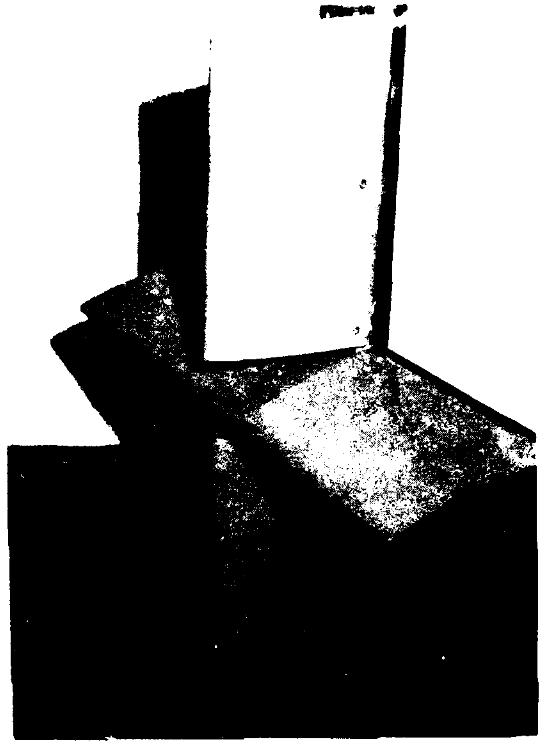
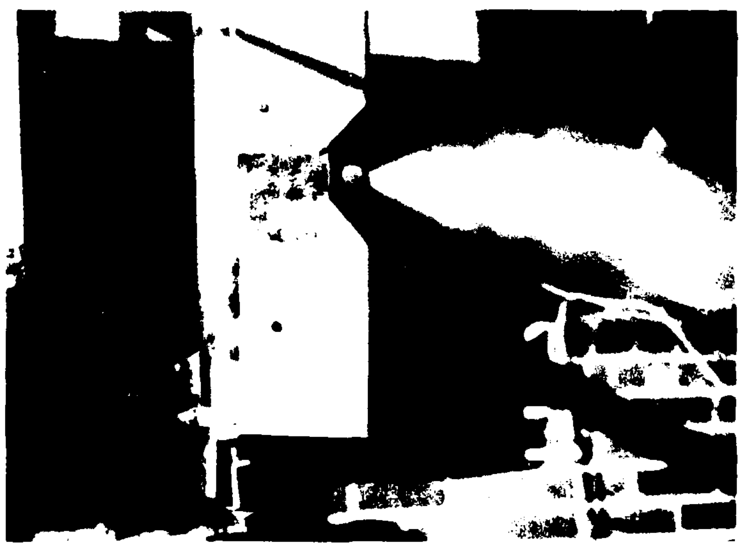
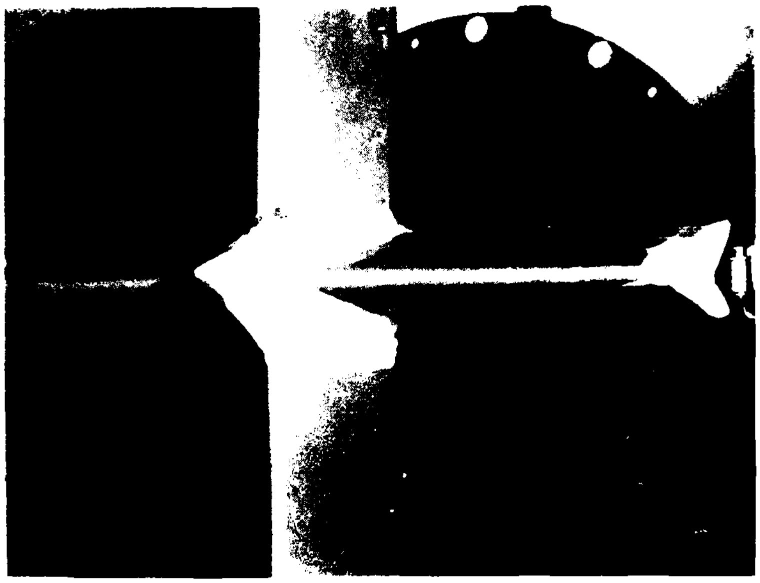


FIG.1 AIRBORNE TALKER MATRIX AFTER SPRAYING FOR 1 HOUR AT -20° C.

FIG.2 TYPICAL ICE BUILD UP ON FAIRING AND NOZZLE IN GROUND ICING RIG.







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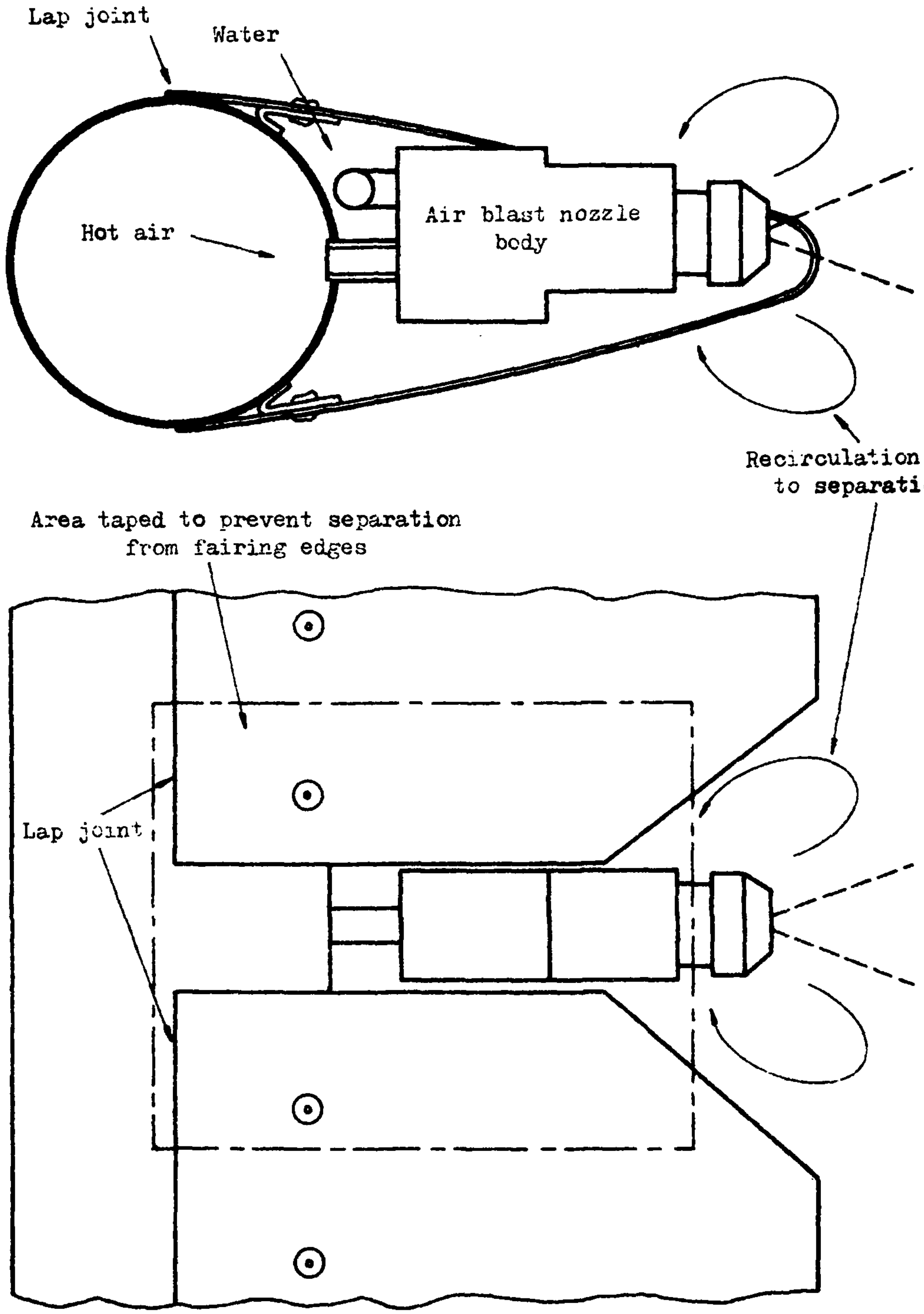
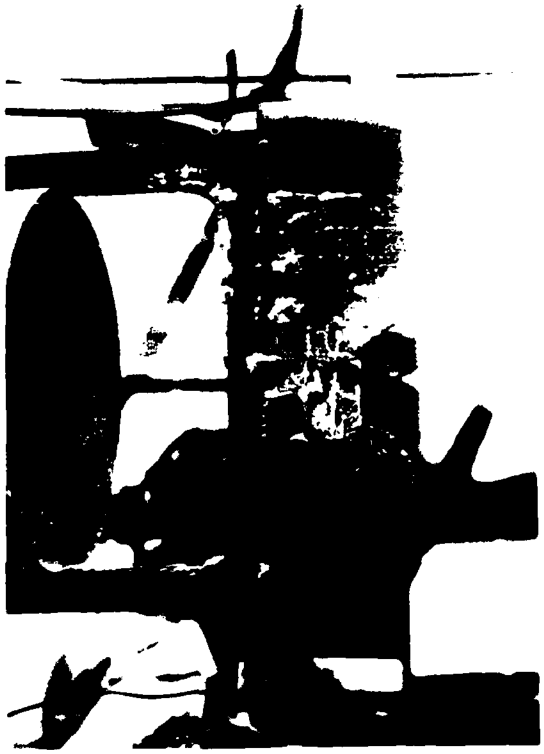


FIG.6 NOZZLE MODEL ARRANGEMENT.



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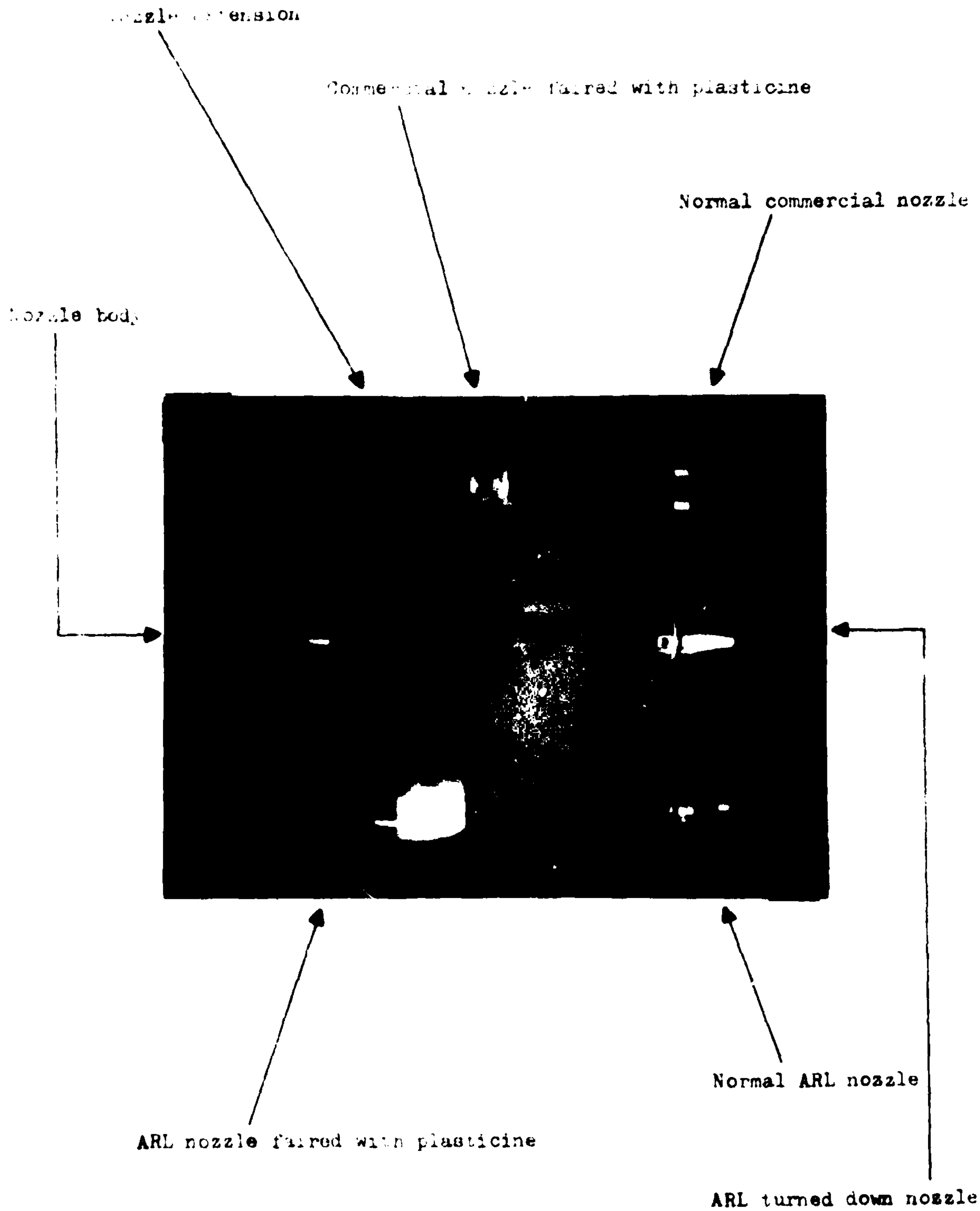

FIG.8 NOZZLE COMPONENTS AND MODIFICATIONS.

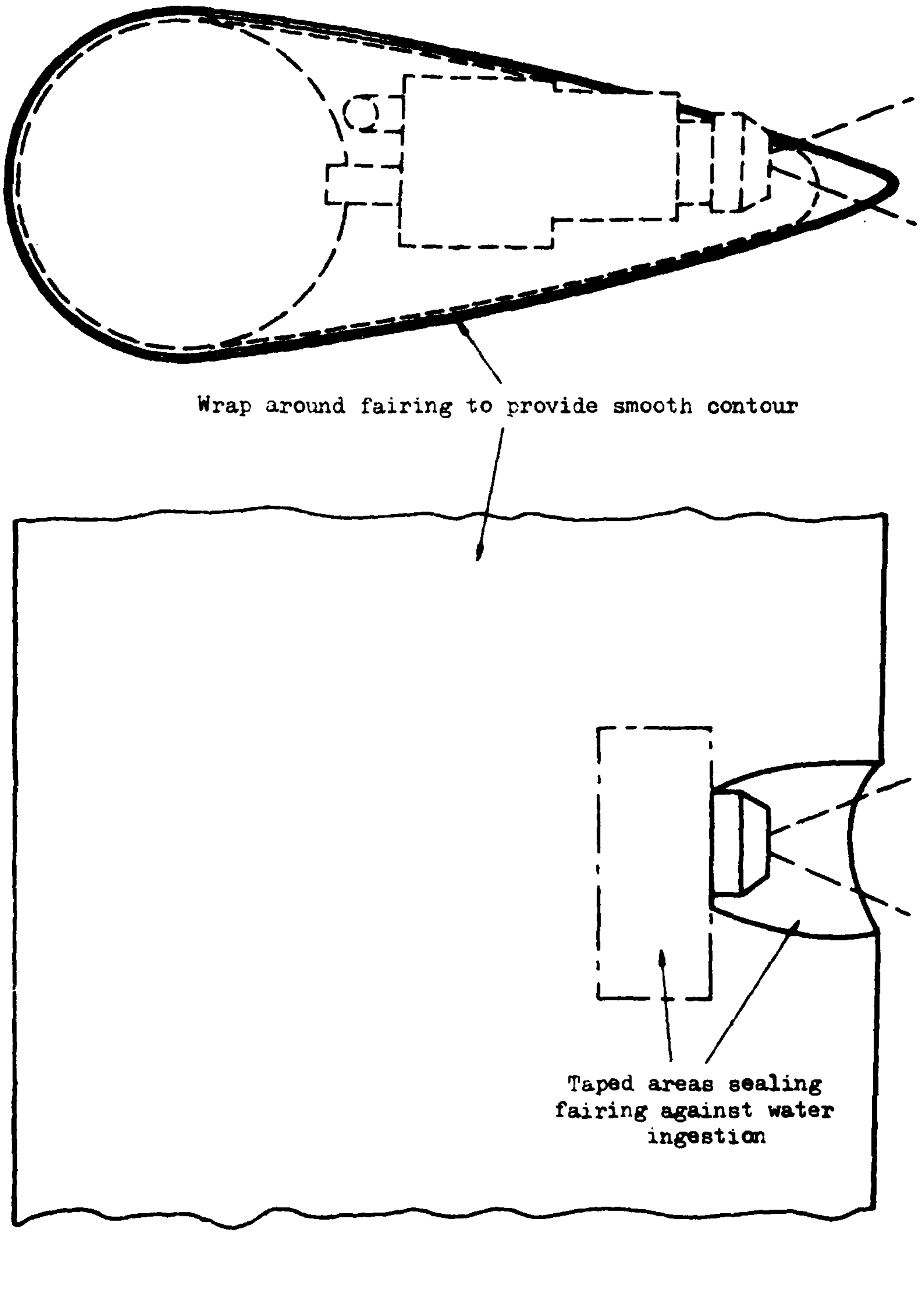

FIG.9 SUCCESSFUL MODIFICATION TO PREVENT ICE BUILD UP.

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